Ku-Band Receiver and Transmitter for Breadboard DSP Scatterometer[1]

Dorothy K. Stosic
Jet Propulsion Laboratory,
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA. 91109
818-354-1657
dkstosic@jpl.nasa.gov

James P. Lux
Jet Propulsion Laboratory,
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA. 91109
818-354-2075
jimlux@jpl.nasa.gov

Abstract- The design and testing results for the Radio Frequency (RF) portion of a breadboard polarimetric scatterometer operating at 13.402 GHz are presented. An integrated breadboard has been developed at Jet Propulsion Laboratory (JPL) to evaluate a programmable Digital Signal Processing (DSP) approach for a follow-on scatterometer similar to SeaWinds (scheduled for launch in winter 2002). Early breadboards of an integrated system have been identified as being a valuable asset in developing effective subsystem requirements for the eventual flight instrument. Many compatibility and partitioning issues between the RF and DSP hardware are actively addressed with the empirical results derived from such a breadboard. The RF portion of the breadboard described consists of a dual channel receiver, converting the received signal at 13.402 GHz to the IF of 37 MHz for the analog to digital conversion, and a single channel transmitter, that converts the I/Q baseband transmit waveform up to Ku band. The breadboard makes provision for emulating capabilities such as programmable attenuators, loop-back calibration, and saturation effects in an actual instrument's power amplifier. It also provides control interfaces to allow early verification of software control algorithms.

TABLE OF CONTENTS

1. INTRODUCTION

The Jet Propulsion Laboratory is investigating the design of a polarimetric Ku-band Scatterometer using general purpose Digital Signal Processors (DSP) to perform the waveform generation, echo processing, and instrument control functions. Part of this effort included the implementation of a breadboard instrument composing the RF and digital processing areas.

The early integration of RF and digital processing provides great benefit for a number of reasons. Design/performance tradeoffs can be evaluated, areas requiring particular attention during the requirements flow-down process can be identified, and design engineers get early experience working with the "box on the other side of the wall" are just a few to mention. The latter aspect is particularly important as it facilitates identifying peculiarities and idiosyncrasies, some of which are obvious to specialists working on their own hardware, but not at all obvious to the person on the other side of the interface. When the time comes to make performance and cost tradeoffs between subsystems, everyone involved will be better informed on the implications of those tradeoffs, which ultimately result in saved time and money for the project.

[1] 0-7803-6599-2/01/$10.00 © 2001 IEEE

The transmitter and two receivers that were assembled for the polarimetric[2] scatterometer were done so as an aide to test the DSP hardware. The RF hardware took the place of lab equipment, which was simulating a radiating spacecraft. This Commercial Off-The-Shelf (COTS) radar forced the engineers to deal with spurious interactions between the analog to digital interface that could potentially arise when eventually building the actual flight instrument. It also validated that a polarimetric radar could be built with enough precision to eventually fly.

2. WHAT IS SCATTEROMETRY?

Scatterometry is the study of the reflection or scattering effect produced while scanning the surface of the Earth from an aircraft or satellite [1]. More specifically, the current orbiting scatterometer is a microwave radar that measures near-surface wind speed and direction over 90% of the world's oceans in a single day. It does this by measuring ocean backscatter cross-sections, σ_o, [2], which are sent to the National Oceanic and Atmospheric Administration (NOAA) within two hours where scientists use it for timely weather forecasting [1]. Figure 1 is a map Jet Propulsion Laboratory (JPL) has produced from scatterometer data, which depict strength and direction of wind by the use of the arrows and various colors.

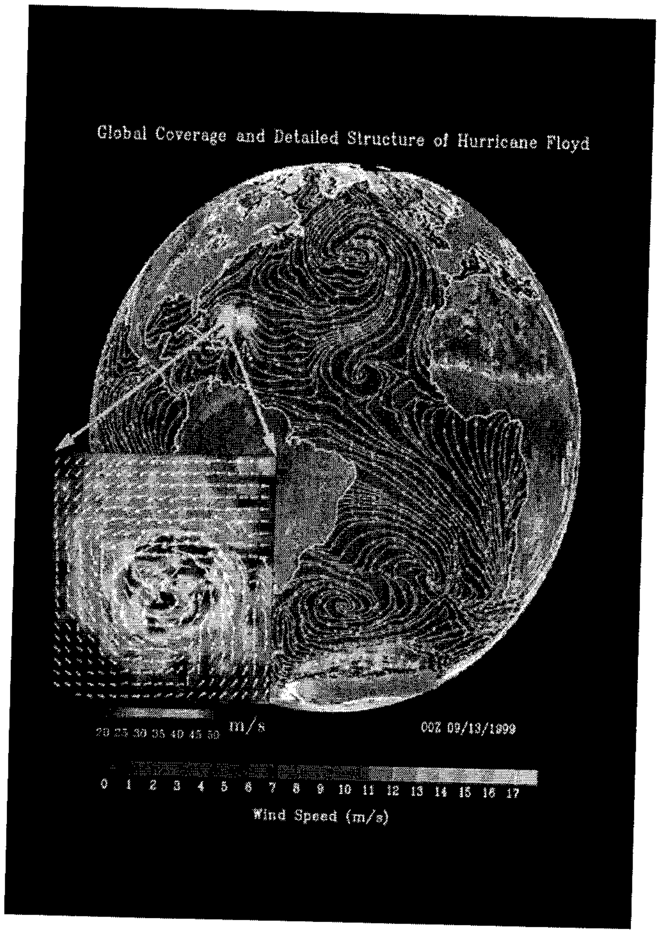


Figure 1: Generated map of wind speed and direction

3. DESIGN GOALS AND REQUIREMENTS

Nominal design goals for the entire instrument breadboard were set to take advantage of earlier work on evaluating insertion of COTS RF MMICs [3] and a novel hybrid DSP processor [4] into the next generation scatterometer. The breadboard RF performance requirements were quite undemanding, (See Table 1). They included necessary functions of translating baseband transmit waveform signals from the digital processor to Ku band and a similar translation from Ku band back down to a low IF in a pair of matched receiver channels for subsequent digital echo processing. An external Ku-band loopback was provided, similar in function (but not precision) to the current instrument, facilitating the evaluation of calibration techniques, particularly for determining the phase shift between receiver channels. Overall, this demonstrated feasibility of a polarimetric breadboard radar.

Beyond the basic frequency conversion functions, it was important to replicate the control signals (See Table 2) expected in an actual implementation, so that various DSP based instrument timing and control functions could be evaluated. Integration of the "signal processing" functions and instrument

[2] Polarimetry simultaneously collects vertical (V) and horizontal (H) data, instead of current scatterometer systems, which alternate between V-H-V-H etc. A polarimeter has the benefit of better ocean coverage, while introducing less error.

Criteria	Requirements	Test Results
Temperature Range	-30 to +85 (degree C)	-30 to +85 (degree C)
Difference of Phase Between Receivers	+/- 10 (degrees)	+/- 6(degrees)
Noise Figure	<= 4dB	4dB
Input Frequency	13.402GHz	13.402GHz
Difference of Gain Between Receivers	+/- 4dB	2.5dB
Dynamic Range	>= 30dB	>40dB
Power	<= 40dB	40dB
Transmitter I & Q	3.5MHz @ -5dBm	3.5MHz @ -5dBm
Output IF (to DSP)	37MHz @ 0dBm	37MHz @ 0dBm

TABLE 1

control in the DSP was expected to be an area of some concern. Finally, the RF breadboard portion provides a reference oscillator from which the DSP processor and various sampling clocks are derived.

Control Signals
Beam Select
Transmit Polarization Select
Receiver Gain Select
Transmit/Receive

TABLE 2

4. RF DESIGN

The polarimetric RF transmitter and receiver processes horizontal (H) and vertical (V) backscatter simultaneously instead of alternating between the two, as in previous orbiting systems. It accomplishes this task by utilizing two receivers instead of one. By processing the data in this way, the same amount of information can be obtained in half the number of "looks" [5]. With half the amount of data to process but with the same amount of information, decreases the amount of error introduced.

The signal processing of the scatterometer has a resolution of a few tens of hertz out of the 13.402 GHz nominal center frequency (i.e. ~2 ppb). In the actual flight instrument, where all the local oscillators (LO) are generated from a common reference, frequency changes due to reference oscillator drift tend to cancel out. However, in a breadboard environment, where standard test equipment is used for diagnosis, evaluation, and software debugging, the frequency drift between the breadboard oscillator and the internal reference(s) of the test equipment can prove to be quite a problem.

In the case presented, all test equipment (frequency counter, spectrum analyzer, signal generators, etc.) is controlled with a 10 MHz reference derived from one of the counters, providing a basic stability of 13 ppb per day. The 81 MHz quartz reference oscillator in the RF breadboard has a stability of 0.2 ppm and an aging rate of 13 ppb/day, as measured by comparison with a cesium reference over 3 days. Comparing the 81 MHz quartz reference oscillator with the 10 MHz test equipment reference over 3 days shows that the two are virtually identical, making it difficult for the 10MHz to accurately show any change. Refer to Figure 2 for more details.

The polarimetric receiver uses the imaginary component of the correlation between the co- and cross-polarized echoes as the significant measurement to reduce ambiguity and provide improved wind retrieval performance. The real component is highly correlated with the copolarized return, and doesn't provide much additional information. However, the resolution of the correlation into real and imaginary components is complicated by any differential phase shift between the two receiver channels, which results in a rotation of the correlation. Preliminary calculations indicate that differential phase must be known to better than 10 degrees. Calibration can be used to provide phase difference knowledge, but good design would minimize the differential phase shift between channels, particularly over temperature.

The design chosen to accomplish this task has several stages. First the front-end has approximately 40dB of gain at Ku-band, which

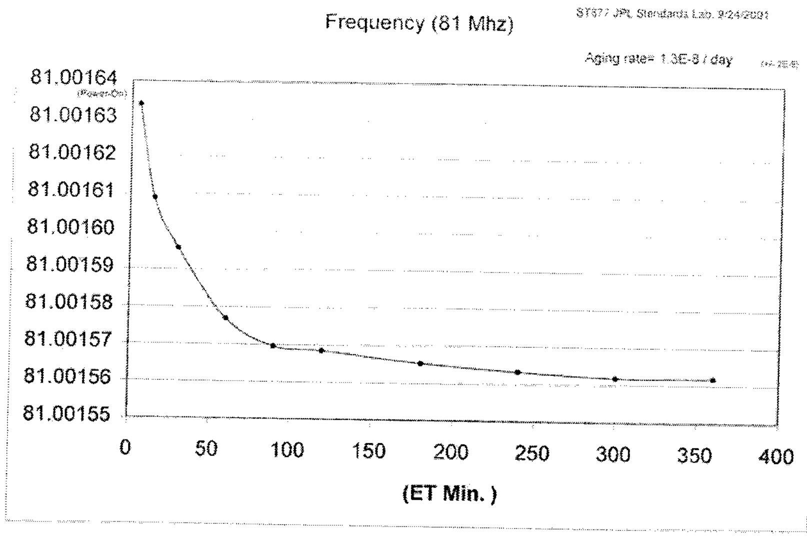


Figure 2: Measured 81MHz aging rate of 13ppb/day.

is mixed down to the Direct Broadcast System (DBS) range in its first conversion. After some filtering and amplification, the DBS signal is then converted to baseband where it is first converted to a digital signal and then sent to one of the multiple DSP for processing[3].

The transmitter portion produces the necessary frequencies required to operate the system, while receiving input from the DSP. It simultaneously sends these manufactured frequencies to the receiver while the digital output from the DSP hardware is received. From here the transmitter mixes it with a Ku-band signal to produce the transmitted frequency of the scatterometer at 13.402GHz. In the receiver portion, it is then downconverted to baseband and sent back to the DSP, where it completes the loop. Figure 3 and Figure 4 are block diagrams of how the transmitter and two receivers work together with the multiple DSP, and of the breadboard layout, from the radar to spacecraft interface, respectively.

To verify that the radar was performing as

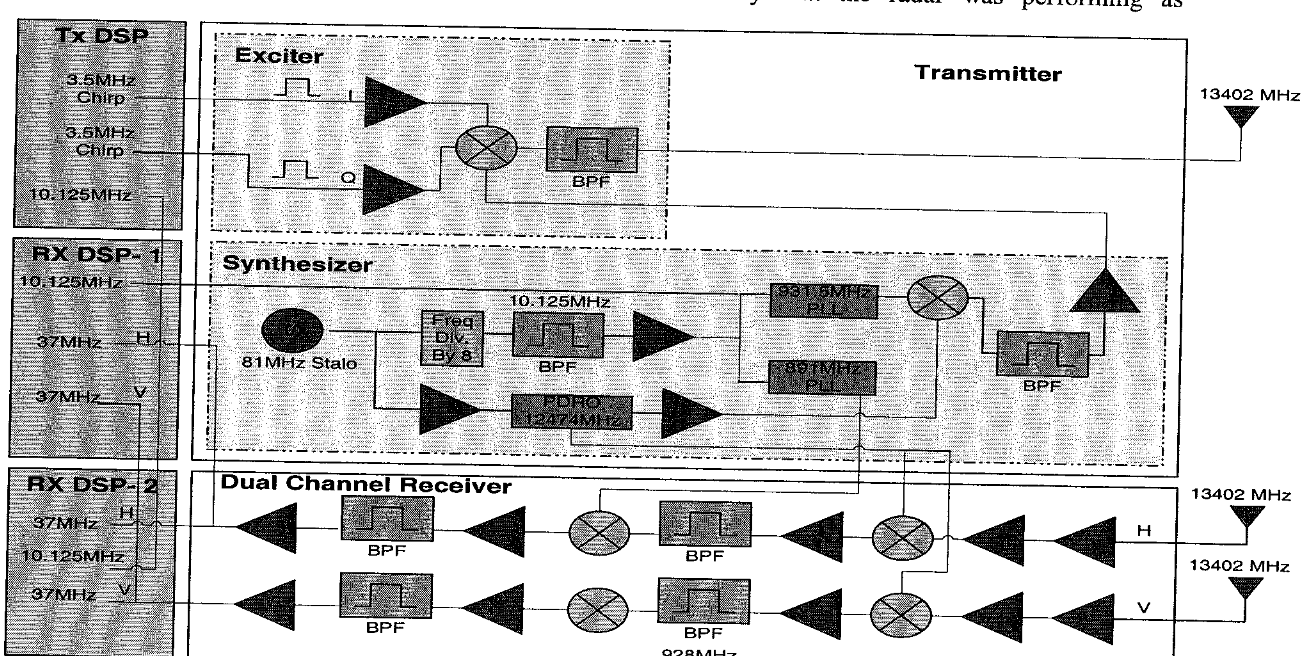


Figure 3: Radar Block Diagram with DSP's.

[3] Multiple DSP are required because the time it takes to process one pulse from the S/C takes longer than the time between pulses. If only one DSP were used, the pulse rate would have to substantially be reduced, resulting in less data.

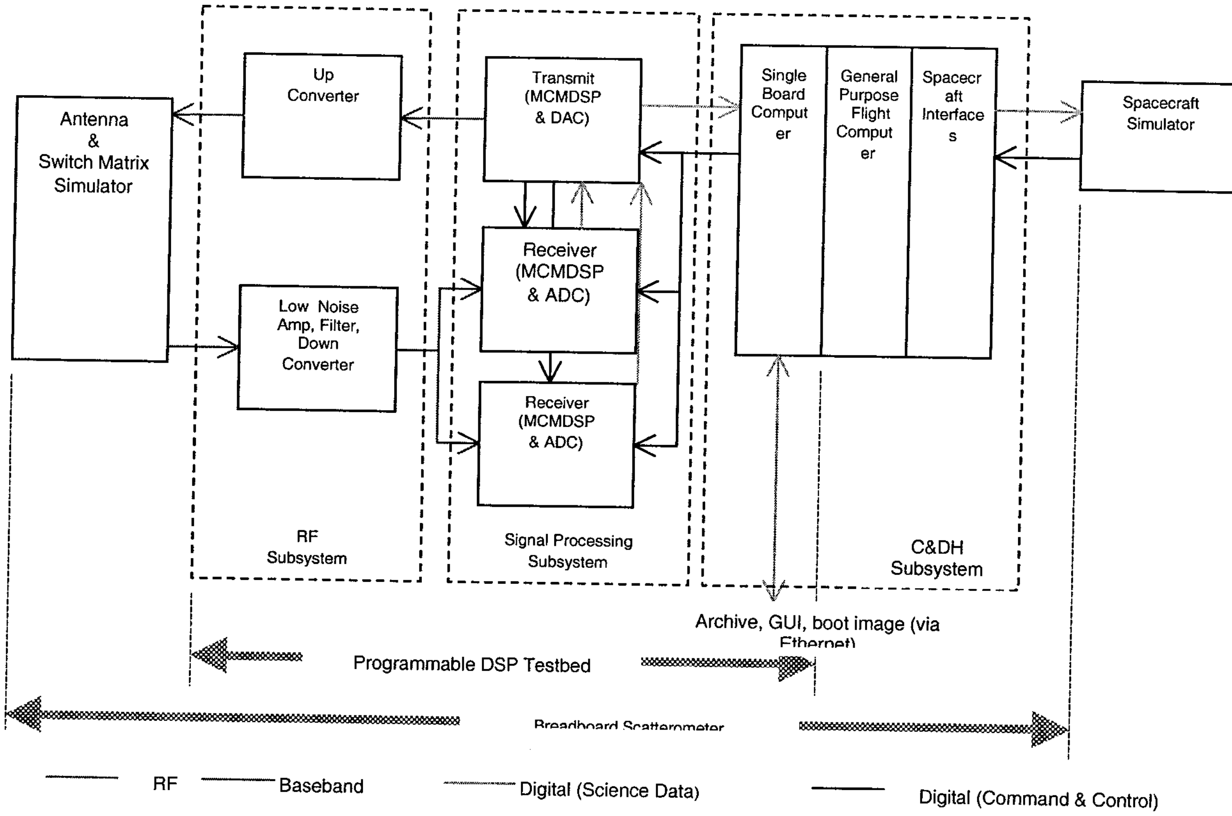


Figure 4: Programmable DSP Testbed and Breadboard Scatterometer

expected, a working simulation of the spacecraft was needed. To accomplish this task, a WR-62 waveguide flange was attached to the output of the transmitter, to act as an antenna. The transmitter was powered on and sent the 13.402GHz signal to the receiver where it was detected, after propagating through air. (This is similar to the spacecraft transmitting and having the ground station receive the signal, on a smaller scale). The output of the receiver, which normally is sent to the DSP, was then looked at on an HP8563E Spectrum Analyzer, where it was shown that the two devices were indeed working as intended. From this, the dynamic range was calculated to be greater than 40dB, which was expected. Figure 5 is a block diagram of the test setup and the results at 37MHz can be seen in Figures 6A and 6B.

5. BREADBOARD DESIGN AND ASSEMBLY

The breadboard design primarily consists of two aluminum boxes, which were used to house the radar: One box for the transmitter and the other for the two receivers. However, since the design is a breadboard and was never meant to be flight quality, it was built to merely test design concepts. Consequently, the selected design partly used components in previous evaluations [3], while the rest were surplus from other projects. Given the relaxed RF performance requirements (As seen in Table 1), the cost effective measures were tolerated. More important, was providing realistic functionality and interfaces to the digital subsystem than salvaging every last tenth of a dB of noise figure.

In the breadboard, the two receiver channels were built on opposite sides of a thick (3.175

mm) aluminum sheet, held down with 3M© double-sided tape facilitating rearrangement of the parts if necessary. The parts were laid out in a mirror image, so they can be expected to have very similar temperature distributions. It made the design easy to troubleshoot, and extremely accessible.

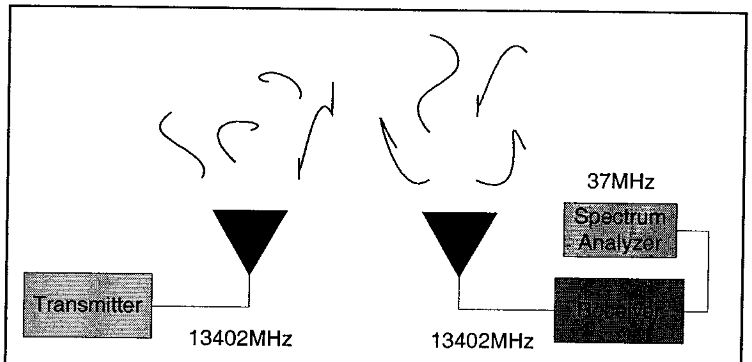


Figure 5: Block Diagram of lab test setup.

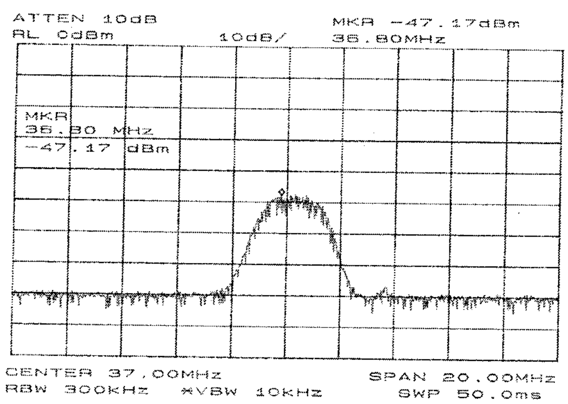


Figure 6a: Spectrum Analyzer output from receiver at 37MHz without RF

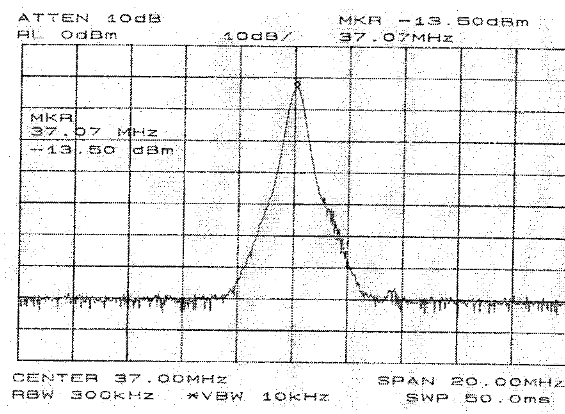


Figure 6b: Spectrum Analyzer output from receiver at 37MHz with RF.

The components were arranged so as to separate the higher frequency components, at Ku-band, from the lower frequencies at baseband. This was done in order to facilitate the feeds coming into and out of the box, which were either passed to the DSP or were coming from the transmitter. This setup allowed for the shortest possible connections, which minimized loss between the receiver box and the next destination. Figure 7 is a photograph of the receiver box.

Preliminary tests of the receiver indicate good matching and tracking of phase, however, further measurements over temperature are planned, to assess the magnitude of the phase variations that might have to be calibrated out in a flight instrument.

The transmitter box was designed next. The transmitter primarily consists of the 81MHz reference oscillator and the frequency synthesizers. By having all of the generated frequencies isolated to one box, it was easier to determine where drifts and other spurious outputs were derived. This is also closer to the actual spacecraft configuration, which kept the theme of producing as close as possible, an actual system. As with the receiver, output frequencies were carefully assembled so as to maintain the shortest possible cabling distance between the two boxes. Figure 8 is a photograph of the transmitter.

6. FUTURE OPTIONS

The scatterometer breadboard provides a number of useful capabilities, particular in the early stages of instrument design. Historically, subsystems are developed essentially independently of each other (often by different contractors), relying on the early partitioning and subsystem requirements being "correct." The breadboard allows some "real-world" experience

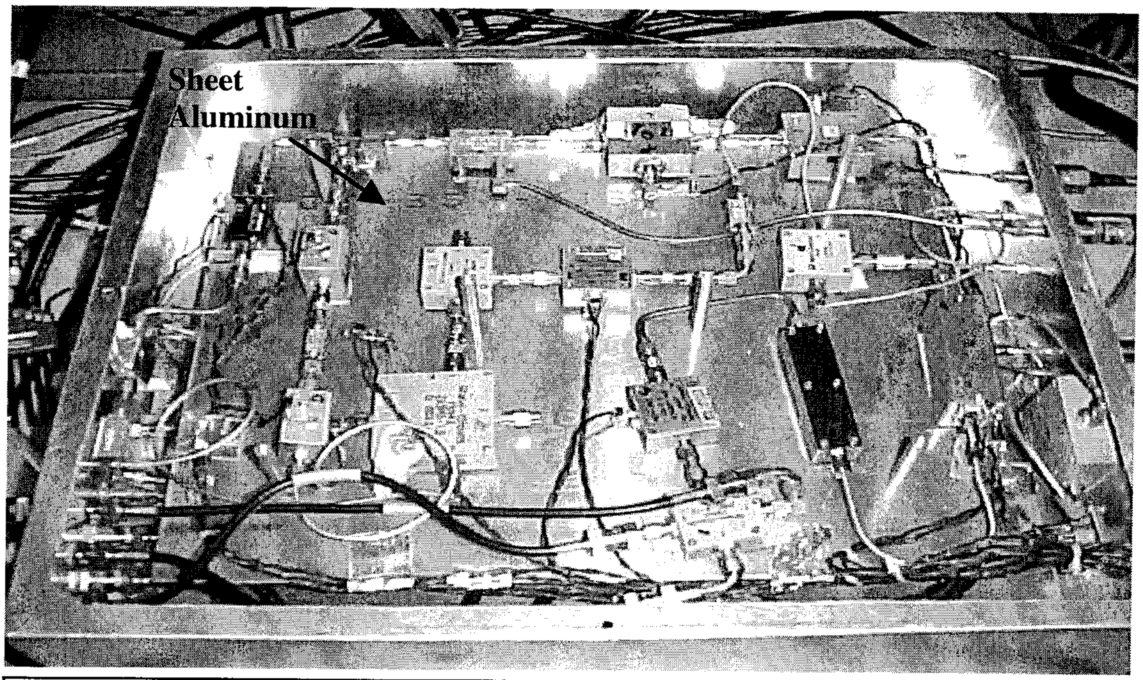


Figure 7: Photograph of inside the receiver box. One receiver is shown, with second hidden under aluminum sheet.

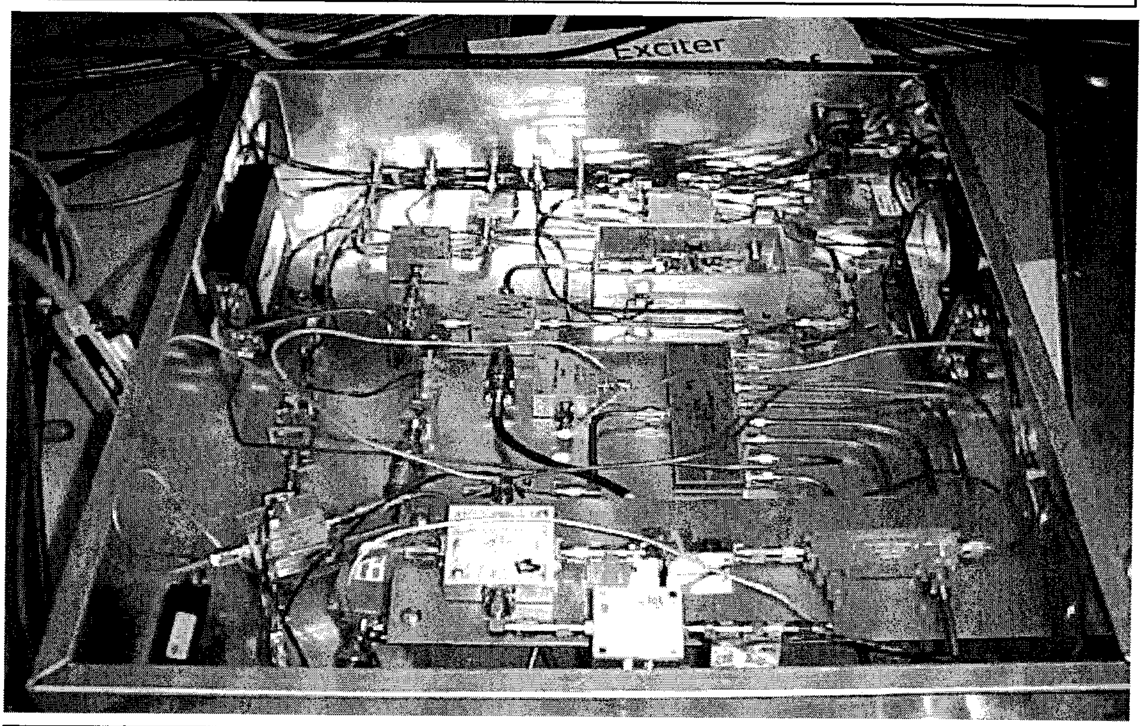


Figure 8: Photograph of transmitter box.

to aid in making those partitioning and requirement decisions.

Integration of RF and digital hardware has traditionally been a source of unforeseen problems leading to schedule and budget problems. Starting with an integrated system from the start, even one that is admittedly different in detail from the eventual instrument provides insight into potential trouble areas that need to be addressed. Such issues as clock stability requirements, test methodologies, signal leakage and interference can be useful experience when eventually building the flight instrument.

The breadboard provides a way to evaluate fault detection and recovery algorithms. The RF design was chosen to be similar to the nominal instrument design, in terms of mixing plan, levels, and such. In a breadboard, it is easy to "fail" a component (or connector), and not only get empirical data for the manifestation of that failure, but evaluate a software detection and recovery strategy. Such early testing also identifies the need for additional testpoints to isolate failures or anomalies, particularly during instrument integration and test.

7. CONCLUSIONS

After experimenting with several configurations it appears that the DSP breadboard utilizing the polarimetric radar, is a viable solution to the next generation of scatterometer. While issues such as heat dissipation, radiation effects and partitioning issues still need to be addressed, many major hurdles have been overcome by the assembly of the breadboard.

The breadboard has other benefits in that it provides the engineering team an opportunity to investigate new technology that may prove to be useful. In the months that ensue, new capabilities such as on-board calibration and programmable attenuators will be evaluated. Without the convenience of the combination radar and DSP breadboard, these and many other issues go unaddressed until the end, where the opportunity to add additional new technology is missed.

Lastly, the breadboard provides an opportunity to investigate new technology at a fraction of the cost, utilizing COTS parts. Building a breadboard model goes through several stages before an accepted form is chosen. By utilizing inexpensive COTS parts first, in place of higher quality flight parts, overhead for the project stays low.

ACKNOWLEDGMENTS

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Special thanks should be given to Quintin Ng, Kermit Pederson, Douglas L. Price and Kathleen Sowles for their hard work, which helped moved the project to completion.

REFERENCES

[1] http://winds/scatterometry/scatindex.html

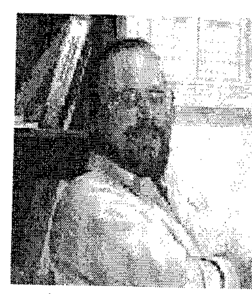
[2] M.W. Spencer, C. Wu and D.G. Long, "Tradeoffs in the design of a spaceborne scanning pencil beam scatterometer: Application to SeaWinds," IEEE Transactions Geoscience Remote Sensing, Vol. 35, pp 115-126, Jan. 1997.

[3] Dorothy Stosic, William Hatch, James Lux and Robert McMaster, "Utilizing Off-the-Shelf Parts for the Next Generation of Space Exploration," IEEE Aerospace Conference, Big Sky, Montana, March 2001.

[4] Alex Bachmann, Douglas Clark, James Lux and Richard Steffke, "Multiprocessor Digital Signal Processing on Earth Orbiting Scatterometers," IEEE Aerospace Conference, Big Sky, Montana, March 2001.

[5] Wu Yang Tsai, Son V. Nghiem, James N. Huddleston, Michael W. Spencer, Bryan W. Stiles and Richard D. West, "Polarimetric Scatterometry: A Promising Technique for Improving Ocean Surface Wind Measurements from Space," IEEE Transactions on Geoscience and Remote Sensing, Vol. 38, No. 4, July 2000.

Dorothy K. Stosic received her B.S.E.E at California Polytechnic University, Pomona in 2000. Dorothy's multi-faceted life includes world travel, renovating old houses, and just having fun. She is currently employed as a RF Design Engineer with the Jet Propulsion Laboratory, in Pasadena, California.



James P. Lux is in the Spacecraft Telecomunications Section at JPL. Design of scatterometers is only one of Jim's diverse interests, which range from man-made tornadoes to solar eclipses to high performance digital radio links.